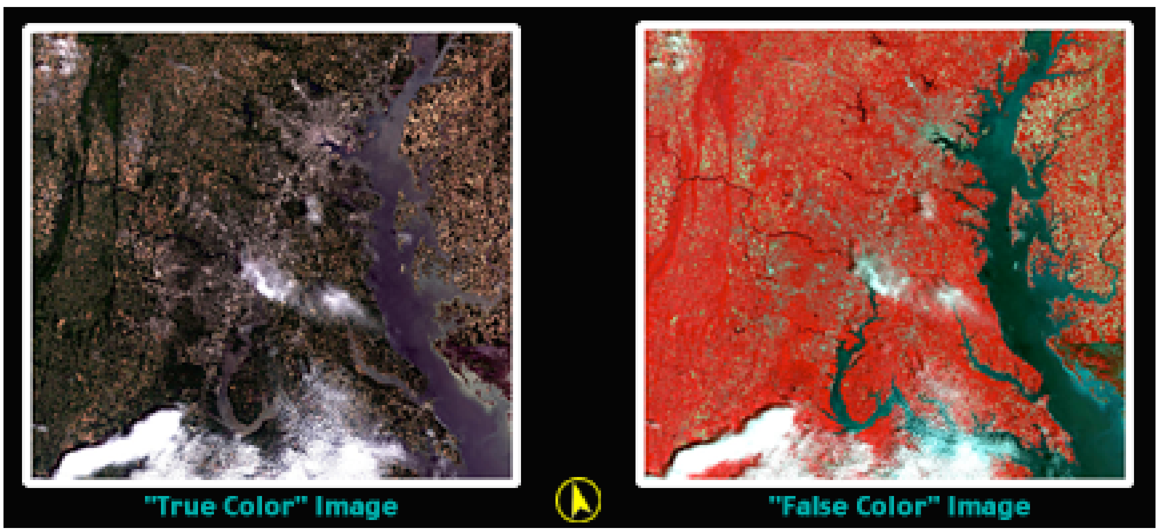
How are satellite images different from photographs?

Many of the satellite images we see have very different colors than the ones we are used to seeing with our own eyes.

Why do satellite images look so different?

Below are two pictures of the exact same location. The picture on the left is a "true color" image; this means that the picture shows objects in the same colors that your eyes would normally see. The picture on the right is a "false color" image; this means that the colors have been assigned to three different wavelengths that your eyes might not normally see.



Images above show the Chesapeake Bay and the city of Baltimore.

To better understand this concept, it might be helpful to first study electromagnetic radiation. All objects emit radiation, albeit in various amounts and at differing wavelengths. Radiation travels in a wave-like manner and the distance between wave peaks is known as the wavelength. When organized by wavelength and frequency, these emissions collectively form the electromagnetic spectrum. Let's learn more.

What is the Electromagnetic Spectrum?

You probably know that you should wear sunscreen at the beach because of dangerous ultraviolet rays, but do you know what ultraviolet rays are? Can you see them? Maybe you've also heard about infrared sensors used for detecting heat. But what is infrared?

Ultraviolet rays and infrared are types of radiant energy which are outside of the human range of vision. The diagram below shows the entire electromagnetic spectrum from high frequency, short-wavelength gamma rays to low frequency, long-wavelength radio waves. Humans can only see a very small part of the electromagnetic spectrum, the visible spectrum (think of a rainbow).

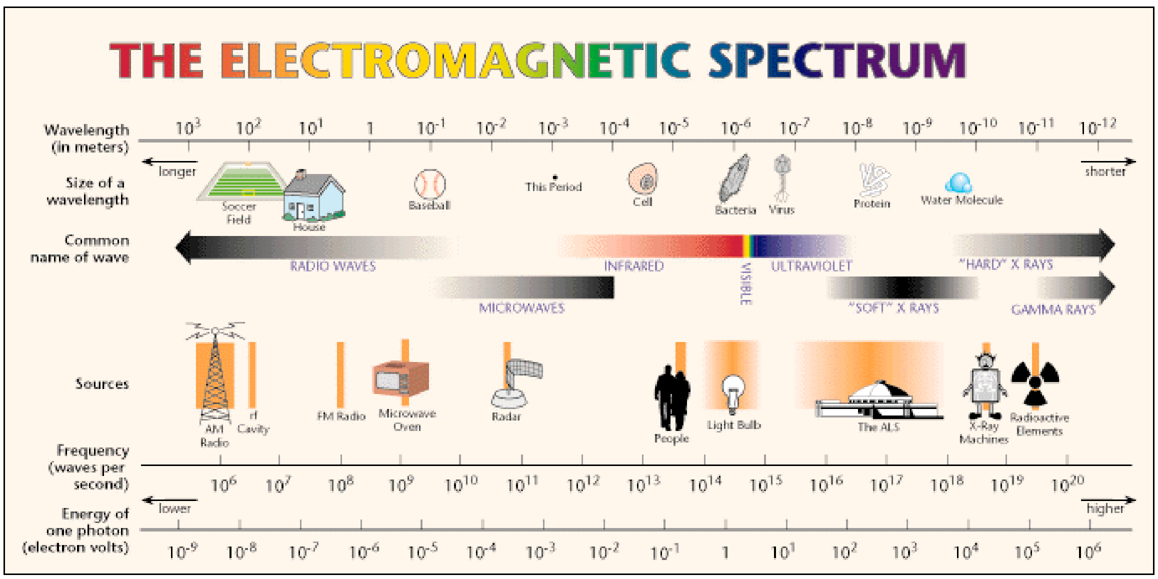


Image taken from World of Beams (http://cbp-1.lbl.gov)

Many insects are able to detect wavelengths that humans are not able to see. Bees, for example, can detect three colors: ultraviolet, blue, and yellow, but not red. The ability to see red is actually rare for all insects. The butterfly is an exception to this rule. Butterflies are believed to have the widest visual range of any animal. Various species of butterfly can detect wavelengths anywhere from 310 nm to 700 nm. To humans, male and female butterflies may look the same, but butterflies are able to identify each other easily because of ultraviolet markings on their wings. Butterflies and insects are also attracted to ultraviolet nectar of certain flowers. The photos below other simulate how humans, bees, and butterflies see the same flower.

Himalyan balsam (policeman's helmet)- Impatiens glandulifera

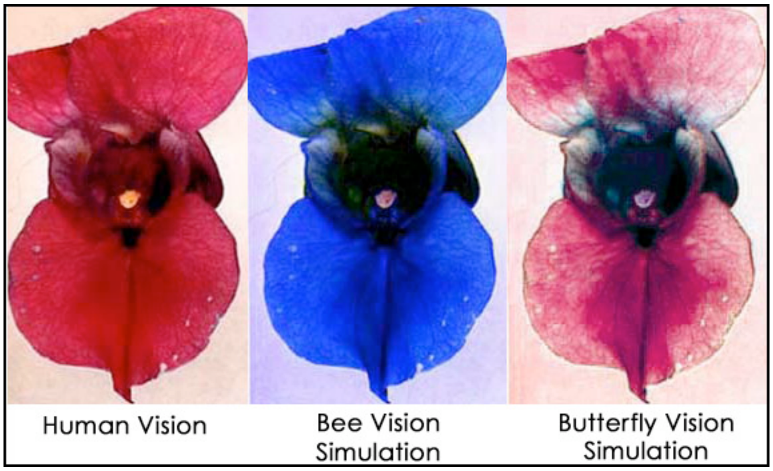


Image taken from The World as Seen By Butterflies

THINK:

1. What light can a human detect, but not a bee?
2. What light can a bee detect but not a human?
3. Is there light the human or bee can detect, but not the butterfly? How can you tell?

The ability to detect light beyond the visible spectrum is not only helpful to insects. Humans can benefit from seeing non-visible wavelengths as well. How is this if we can only see visible light?

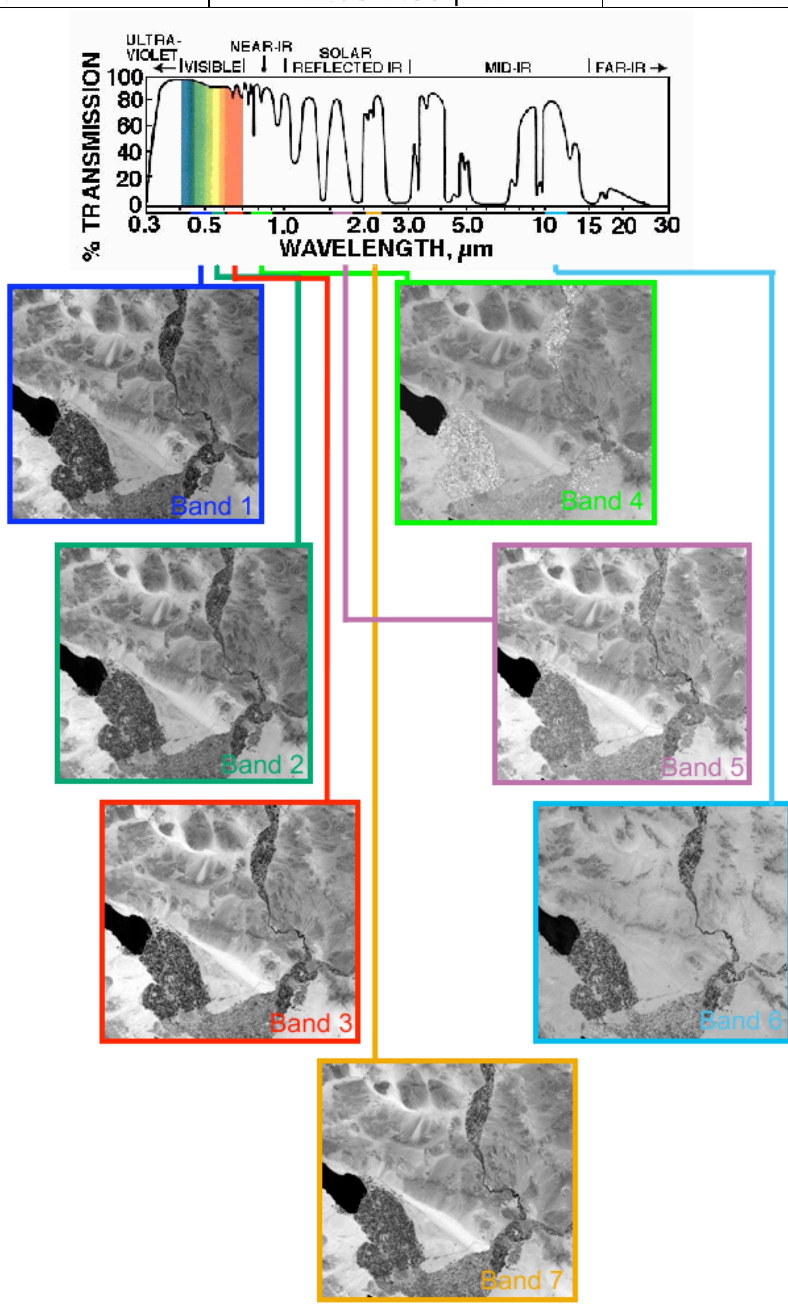
How can we see invisible light?

Humans cannot see light past the visible spectrum, but satellites are able to detect wavelengths into the ultraviolet and infrared. Satellites, like Landsat 7, fly high above the earth, using instruments to collect data at specific wavelengths. These data can then be used to build an image. Satellite instruments are able to obtain many images of the same location, at the same time. Each image highlights a different part of the electromagnetic spectrum.

The Landsat 7 satellite uses an instrument that collects seven images at once. Each image shows a specific section of the electromagnetic spectrum, called a band. Landsat 7 has seven different bands. The table below shows the seven bands of Landsat 7.

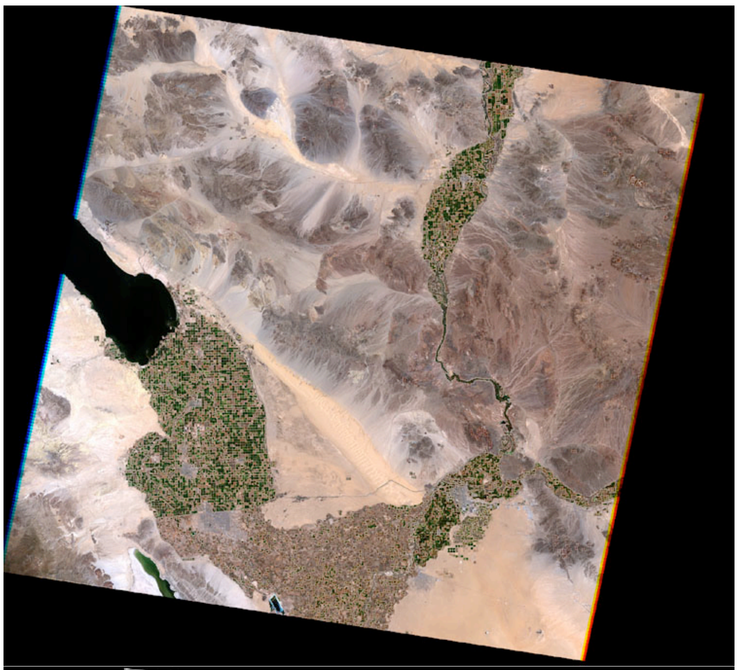
Spectral sensitivity of Landsat 7 Bands.

Band Number	Wavelength Interval	Spectral Response
1	0.45-0.52 µm	Blue-Green
2	0.52-0.60 µm	Green
3	0.63-0.69 µm	Red
4	0.76-0.90 µm	Near IR
5	1.55-1.75 µm	Mid-IR
6	10.40-12.50 µm	Thermal IR
7	2.08-2.35 µm	Mid-IR

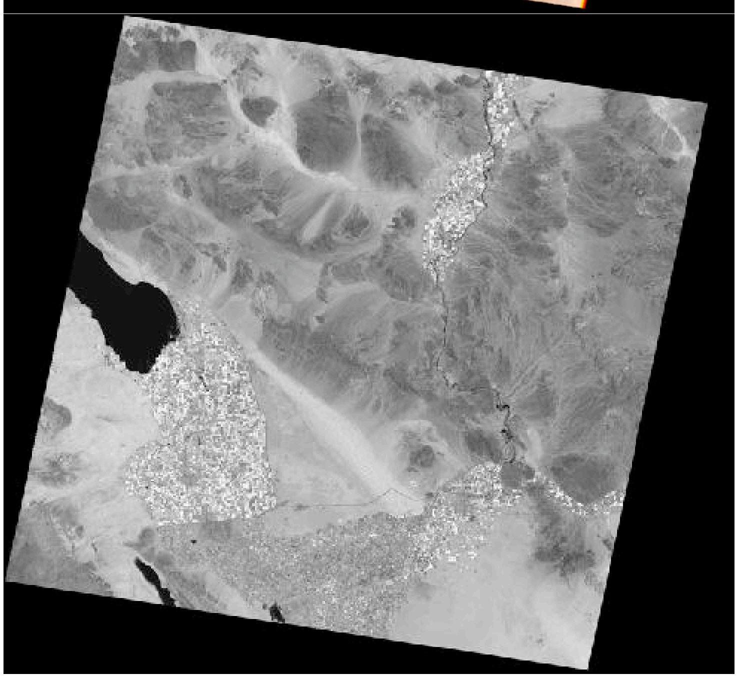


Electromagnetic Spectrum Image from Virtual Hawaii.

Landsat 7 obtained all of the images above at the same time, and at the exact same location. If you look closely at the images, you will see that they do not all look the same. Light and dark spots in the images appear in different places. This is because different objects on earth (plants, soil, water, etc.) reflect different wavelengths of light. The bright spots on the images show where a lot of light is being reflected.



The image to the right is a "true color" image of the desert around the Salton Sea and Imperial Valley in Southern California. The American/Mexican border is clearly visible.



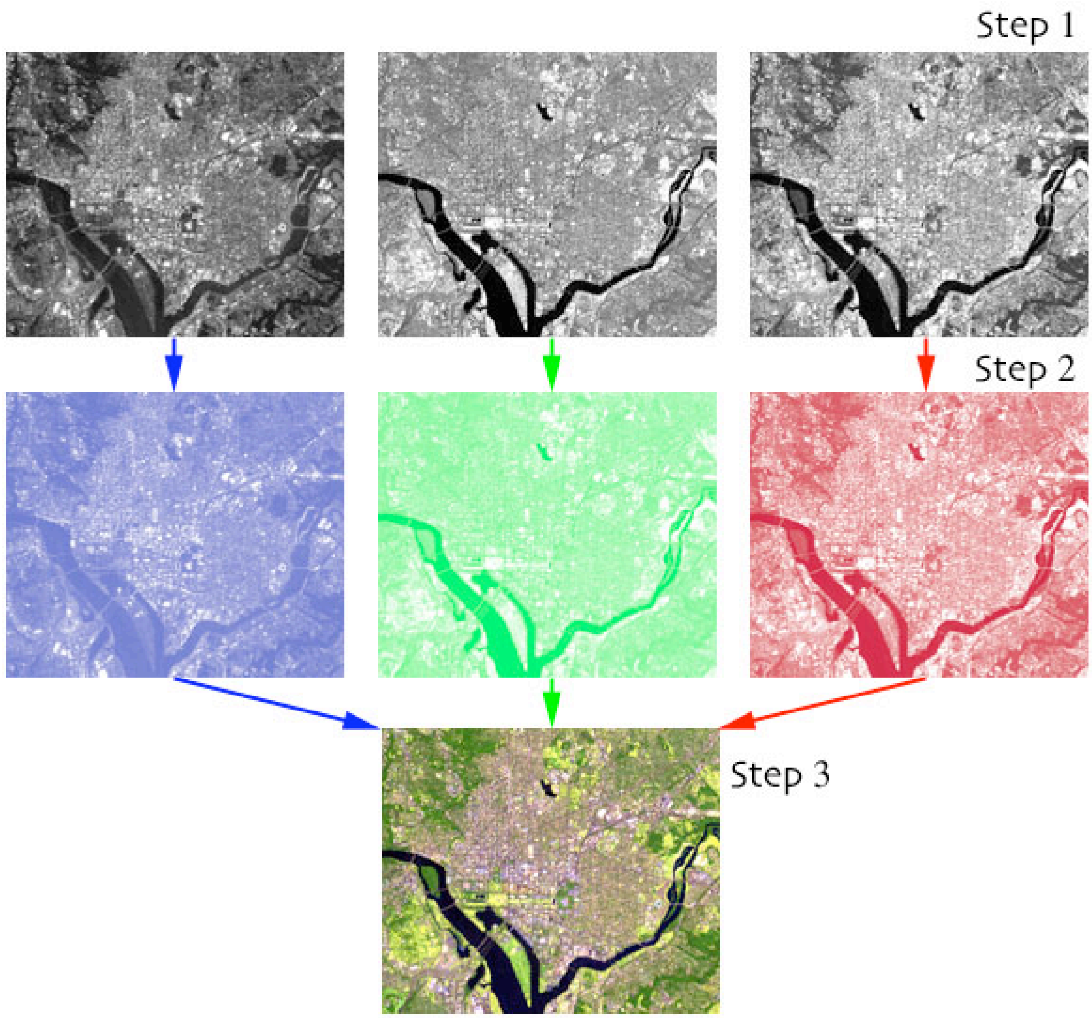
In this Band 4 image, the light areas indicate strong reflection of wavelengths between 0.76 and 0.90 µm; the darker areas do not strongly reflect in those wavelengths. What do you think the light areas are?

Landsat 7 Band Number	Application
1	coastal water mapping, soil/vegetation discrimination, forest classification, man-made feature identification
2	vegetation discrimination and health monitoring, man-made feature identification
3	plant species identification, man-made feature identification
4	soil moisture monitoring, vegetation monitoring, water body discrimination
5	vegetation moisture content monitoring
6	surface temperature, vegetation stress monitoring, soil moisture monitoring, cloud differentiation, volcanic monitoring
7	mineral and rock discrimination, vegetation moisture content
For more details see: Lillesand, T. and Kiefer, R., 1994. Remote Sensing and Image Interpretation. John Wiley and Sons, Inc., New York, p. 468.	

How are color satellite images created?

Satellites acquire images in black and white, so how is it possible to create the beautiful color images that we see on television, in magazines, and on the internet? Computers provide us with the answer.

Remember that images created using different bands (or wavelengths) have different contrast (light and dark areas). Computers make it possible to assign "false color" to these black and white images. The three primary colors of light are red, green, and blue. Computer screens can display an image in three different bands at a time, by using a different primary color for each band. When we combine these three images we get a "false color image".



To really understand a false color image, we must know which band was assigned to each of the three colors.

Think:

1. Why can a false color image only display three bands at a time?
2. Why do we call colored satellite images "false color images"?
3. Why is it important to know which band was assigned to each color in "false color image"?

How do primary colors mix to represent reflection?

RGB = NRG

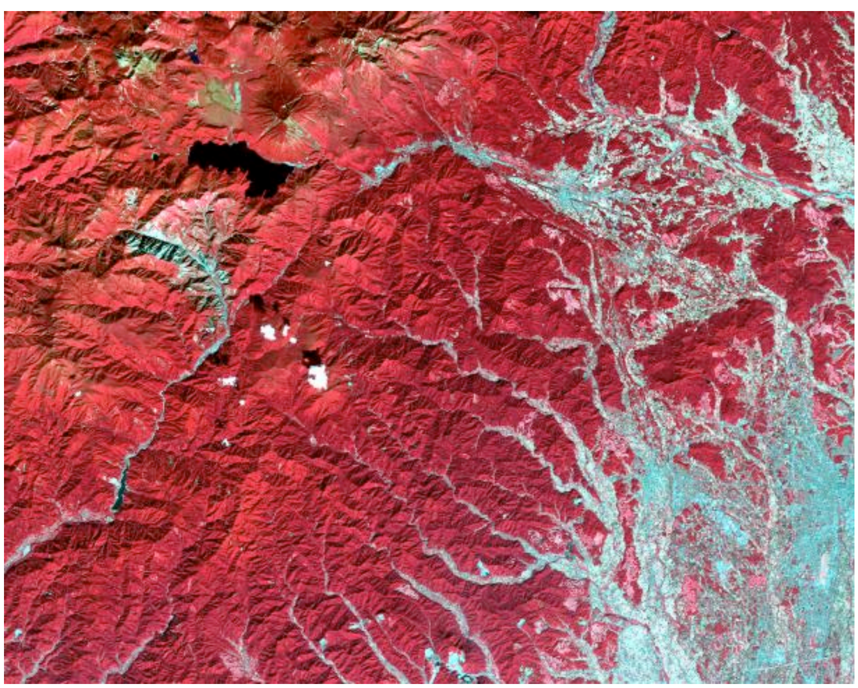
As you know, the three basic components of visible light are red, green, and blue light (RGB). In theory, any visible color can be created combining these colors in some way.

Landsat 7 images are color composites, made by assigning the three primary colors to three bands of the Enhanced Thematic Mapper (ETM+) sensor. These images are not color photographs; they are "false color" images (green fields won't necessarily look green in the image).

One common way that primary colors are assigned to bands can be easily remembered using the mnemonic -

RGB = NRG (Red, Green, Blue = Near Infrared, Red, Green, or "energy")

Red = Near IR (ETM+ band 4)
Green = Red (ETM+ band 3)
Blue = Green (ETM+ band 2)



This image uses Landsat ETM+ Bands 4,3,2.
The image depicts an area just north of Tokyo, Japan.

This common band combination makes vegetation appear as shades of red, because vegetation reflects a lot of near infrared light. The brighter the red, the healthier the vegetation. Soils with little or no vegetation will range from white (for sand) to greens and browns, depending on moisture and organic matter content. Water will range from blue to black. Clear, deep water is dark, and sediment-laden or shallow water appears lighter. Urban areas look blue-gray. Clouds and snow are both white.

This assignment of colors is only one of many possible combinations. Any combination of bands can be represented by red, green, and blue. In the following activity you will have the opportunity to manipulate the seven bands of Landsat 7.

Applications of Landsat Data

False color satellite images can provide extremely valuable information about the world we live in. Just as butterflies benefit from their ability to detect invisible wavelengths, humans can benefit from the technology of satellite imaging.

Geologic Applications
- Statigraphy, Structure, and Mineral and Petroleum Exploration

Vegetation Applications
- Agriculture, Forestry, and Ecology

Urban and Land Use Applications

References

National Science Content Standards (National Research Council)
Virtually Hawaii (http://satftp.soest.hawaii.edu/space/hawaii)
Remote Sensing Tutorial (http://rst.gsfc.nasa.gov)
The World As Seen By Butterflies (courtesy of University of Derby UK)
Remote Sensing Library Piece
World of Beams (http://cbp-1.lbl.gov)
USGS: Earthshots (http://www.usgs.gov/Earthshots)

Answers to THINK Questions

What light can a human detect, but not a bee?
Bees cannot detect red light, humans can.

What light can a bee detect but not a human?
Humans cannot detect ultraviolet light, bees can.

Is there light the human or bee can detect, but not the butterfly? How can you tell?
Butterflies can detect light visible to both humans and bees. You can tell this because the butterfly sees both the red that the human sees and the ultraviolet (shown in blue) that the bee sees.

What do you think the light areas are?
The light areas are vegetation. In band 4 (NIR), vegetation is highly reflective. The human eye cannot perceive NIR light.

Why can a false color image only display three bands at a time?
There are only three primary colors of light: red, green, and blue. All other colors that we see are a combination of these three colors.

Why do we call colored satellite images "false color images"?
The colors in the images are not the ones that we would normally see with our eyes. They are assigned colors.

Why is it important to know which band was assigned to each color in "false color" images?
Without knowledge of how each band has been assigned, we cannot be sure why the colors appear as they do, or what each color identifies.